GROWTH, RELATIVE WATER CONTENT, TRANSPIRATION AND PHOTOSYNTHETIC PIGMENT CONTENT IN COFFEE TREES (*Coffea arabica* L.) GROWING AT DIFFERENT SUNLIGHT REGIMES

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ABSTRACT. The effect of different light regimes (100, 85 and 70 % solar exposition) on coffee plants (*Coffea arabica* L. var. Caturra) was studied. There was an overall effect of solar exposition levels on growth at different crop growth stages, plant height and stem diameter being the most affected variables with higher values in 85 % solar exposition. Relative water content showed daily variations with minimum values at midday for higher exposition level treatments. Transpiration was slightly higher in 100 % level at 11:00 h, and an increased chlorophyll *a* and *b* content was observed in 85 % solar exposition, while carotene content was similar in the three levels. The total chlorophyll *a+b* showed a highest value in the 85 % level of solar exposition. Results indicated some adaptability features of coffee plants to slight shade conditions, because of the constancy observed for chlorophyll *a/b* ratio among solar radiation exposition levels, and the highest vegetative growth showed in moderated shade (85 % solar exposition).

Key words: *Coffea arabica*, growth, solar radiation; plant water relations; transpiration, chlorophylls

RESUMEN. Se estudió el efecto de diferentes niveles de exposición a la radiación solar en el crecimiento vegetativo, contenido relativo de agua (CRA), transpiración y contenido de pigmentos fotosintéticos en plantas de cafeto (*Coffea arabica* L. var Caturra). Los tratamientos consistieron en tres niveles de exposición a la radiación solar (100, 85 y 70 %). Hubo un efecto significativo del nivel de exposición a la radiación solar sobre las variables del crecimiento en su conjunto, siendo la altura de la planta y el diámetro del tallo las variables que más se afectaron por los niveles de luz con mayores valores en la variante de 85 % de exposición. El contenido relativo de agua (CRA) mostró variaciones diurnas con mínimos durante las horas del mediodía para las variantes de mayor iluminación, con valores relativamente altos (>90 %). La transpiración fue ligeramente mayor a las 11:00 h en la variante de 100 % de exposición solar, seguida del tratamiento de 85 % de exposición solar . Se observó mayor contenido de clorofila *a* y *b* en la variante de 85 % de exposición solar; la concentración de carotenoides fue similar en las tres variantes mientras que de las relaciones Cl *a+b* y Cl *a/b*, fue la primera la que presentó diferencias significativas a favor de los cafetos expuestos a 85 % de exposición solar. Los resultados indican que los cafetos muestran características de adaptabilidad a las condiciones de sombra moderada, atendiendo a la poca variación en la relación *cla/clb* y al mayor crecimiento observado bajo sombra regulada (85 % de exposición solar).

Palabras clave: *Coffea arabica*, crecimiento, radiación solar, relaciones planta agua, transpiración, clorofilas

INTRODUCTION

Coffee is one of the most important agricultural products in the international market (1). It is cultivated in different latitudes around the world, but its distribution depends on factors as location, soil types, shading and management practices and it may be a single cultivated species in full sun or might be part of a multi-component system in which coffee plants are shaded as part of an understory stratum. Unshaded plantations, planted at either conventional or high density spacing, represent the most important world-wide system of coffee cultivation, although multi-component systems still exist (2).

One of the most important study themes about the physiology of coffee tree is the effect of irradiance on photosynthesis and productivity. The ability of species to efficiently and rapidly adjust its allocation patterns and physiological environment is the key for determining its growth potential to that specific environment (3).

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The great variation in light environment imposes a great influence on plant response. In coffea genus, the knowledge of the effects of irradiance levels on growth and physiology is important, because this species originated in shaded habitats, but nowadays coffee plants are cultivated in full sunlight in the most important coffee producing country (Brazil), where the plant tends to express all its yield potential, so overproduction and consequent plant exhaustion can occur (4). This agricultural system has been successful due to the high adaptability of coffee plants to different irradiance levels (5, 6). Nevertheless, later studies showed that moderate shading might contribute to maintain yield stability (7, 8).

Coffee plant may be classified as a shade-facultative species, because it has some characteristic features of sun-adapted plant, such as increased growth and photosynthesis capacity, coupled with high light saturation under full irradiance and relatively constant quantum yield in both shade and light environments (6). In addition, coffee displays several shade-acclimation characteristics, including a low chlorophyll *a/b* ratio and structural change as higher specific leaf weight in sun plants (9). On the other hand, high irradiance affected the enzymatic and biochemical reactions of photosynthesis, especially when nitrogen supply was low (10). In Cuba, this type of work is limited and does not exist any reports for the zone where this research was carried out.

In this work, the variations of growth, relative water content, transpiration and photosynthetic pigment content in coffee trees growing at different sunlight levels are discussed.

MATERIAL AND METHODS

The experiment was carried out in a 13 year-old coffee plantation (*Coffea arabica* L. var. Caturra) in the locality of "Los Corrales", Sierra Maestra mountain range, at 250 m above sea level, on a fersialitic soil (11), with a plant density of 5000 trees per hectare.

The treatment imposed consisted of three light levels: 100, 85 and 70 % sunlight exposition. The prune of shade trees to maintain sunlight exposition levels was repeated every year after the end of crop yield phase.

The coffee plantation was renewed by means of stumping, and all measurements were initiated three months after pruning.

Growth measurements. Seven plants per treatment were selected and plant height (PH), branches per plant (BP) and stem diameter (SD) were measured in each plant. Measurements were repeated at three, nine and twelve months after the prune.

Water status measurements. These measurements were made at fruiting phase. The variables relative water content (RWC) and transpiration rate (TR) were taken (12), adjusting the procedures as follows:

- Relative water content (RWC)

Nine samples of ten leaf discs, each one per treatment, was made up. Leaves were taken from the youngest fully expanded leaves of the central plagiothropic branches. Leaf discs were immediately weighed (fresh weight; FW). These samples were floated in distilled water inside the porous platform, in order to obtain turgid weight (TW) at a temperature range between 30-32°C. At the end of imbibition period, leaf samples were placed in a pre-heated oven at 80°C for 48 hours, in order to obtain dry weight (DW). Values of FW, TW and DW were used to calculate RWC, using the equation:

RWC (%)=[(FW-DW)/(TW-DW)]* 100

Measurements were repeated four times within the day, every two hours, from a base value taken at predawn.

- Transpiration

Five leaves per plant were collected in each treatment. The initial leaf fresh weight varied from 100 to 700 mg. After that, the leaves were exposed for ten minutes to natural environment and weighed again to calculate transpiration rate by the difference between the two weights.

Photosynthetic pigment contents. Leaf discs were collected from totally developed leaves located in the third and fifth couples of plagiotropic branches, at the same time of water status measurements. Adjusting leaf area by means of a leaf area coefficient calculated in the laboratory for a hundred leaves, relating, the area (dependent variable) and the product of leaf length per leaf width (independent variable) by means of regression analysis. After crushing leaf tissue with silica sand in a mortar and filtering the sample, the absorbance (at 440, 645 and 663 wavelength) of the extracts was measured in a spectrophotometer using acetone (80 %) as solvent.

The following formulas were used to calculate the concentration of chlorophyll *a b* and carotene:

- Chl *a*=12.7 A663-2.69 A645 ($mg.L^{-1}$)
- Chl *b*=22.9 A645-4.68 A663 ($mg.L^{-1}$)
- Carotene = 4.65 A440-0.268 Chl (*a*+*b*) ($mg.L^{-1}$).

Soil moisture (soil dry weight basis) was registered in each treatment at 0.40 m soil depth during five months, covering the phases of flowering, fruit growth and ripening.

Statistical design and analysis. The experimental layout consisted of three blocks distributed in the field through the following criterion:

- Block 1: 100 % (unshaded plantation from November to April)
- Block 3: 85 % (50 % shade trees were pruned with respect to treatment 1)
- Block 3: 70 % (shade trees were pruned as recommended in the Technical Instruction for Coffee Plantation (13). Measurements of irradiance were taken with a luximeter located at the top of coffee plant canopy to establish solar exposition levels.

Data growth and photosynthetic pigment contents were subjected to a multivariate analysis of variance (MANOVA) and ANOVA respectively. To know the difference between means, a Tukey test at $p \leq 0.05$ was made.

Relative water content and transpiration were graphically analysed showing descriptive statistics.

RESULTS AND DISCUSSION

Growth analysis. Following the criteria of MANOVA procedures, Wilk´s Lambda indicated an overall significant effect of sunlight levels on growth (Table I). Particularly plant height and stem diameter were the most affected variables by sunlight levels, while light levels did not influence the number of branches at the three growth stages and stem diameter at three months.

Table I. Influence of different irradiance levels on growth of coffee trees at different growth stages. Values are averages of seven replicates

Irradiance levels (%)	Height (cm)	Stem diameter (mm)	Number of branch pairs
3 months (Wilk´s λ=0.3924; p<0.05)			
100	5.49 b	4.19	0.82
85	8.78 a	5.43	1.99
70	9.59 a	4.78	1.60
SEx	0.34	0.16	0.15
P level	0.0047	0.22	0.27
9 months (Wilk´s λ=0.3527; p<0.02)			
100	38.70 b	6.15 b	3.95
85	48.26 a	9.64 a	4.61
70	36.47 b	6.61 b	4.18
SEx	0.99	0.19	0.16
P level	0.018	0.00027	0.59
12 months (Wilk´s λ=0.4267; p<0.009)			
100	64.95 b	8.76 b	6.61
85	75.36 a	11.29 a	8.64
70	59.05 b	8.95 b	7.02
SEx	1.93	0.17	0.25
P level	0.013	0.002	0.13

Means followed by the same letter within a column for each growth stage are not significantly different

All three variables were higher in the 85 % solar exposition level than in 100 and 70 %. In the case of PH, the coffee trees growing at 85 % solar exposition were 7 and 19 % higher than in the 100 and 70 % treatments respectively, while in the SD, this difference was notably higher (26 and 24 % respectively).

These results agree with some studies demonstrating that coffee plants grow better and accumulate more dry matter when they are cultivated in moderate shade compared with full sunlight (14); however, similar results in sunlight treatment have been obtained (6). Under shade, bigger branch internodes have been observed, but growth rate varies with water availability and temperatures of both air and leaves (2). Contrarily to those results, other authors have demonstrated that leaf area per plant and plant height in *Coffea arabica* L. decreased 30 and 20 % respectively from 100 to 80 % sunlight exposition but sun plants exhibited higher leaf nitrogen content (5). Other authors attributed the low leaf area in sun plants to the highest leaf abscission, mainly during fruit development stages (14). Probably, these contradictory results could be related with differences in the locality characteristics as soil types, ecological or environmental conditions and to the experimental conditions, because most of the results mentioned above have been obtained under controlled conditions.

Since coffee evolved under low water stress conditions (Figure 1), coffee species are not particularly drought resistant (2); but taking into account the high relative water content (>90%) observed in all three sunlight levels (Figure 2), it is not probable that the differences in soil moisture could be the main causes of that difference in growth. In Brazil, the decline of vegetative growth was observed in both irrigated an non-irrigated plants, and did not show a direct relation with leaf water potential (4).

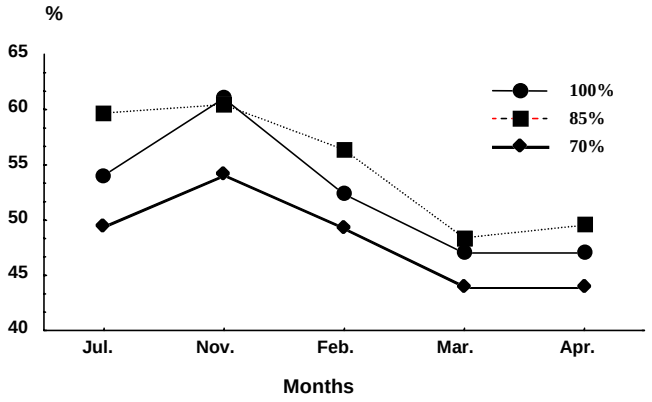

Figure 1. Soil moisture (dry soil weight basis) at different sunlight levels during the measurement period. SE represents the standard error. Each mean represents an average of six replicates

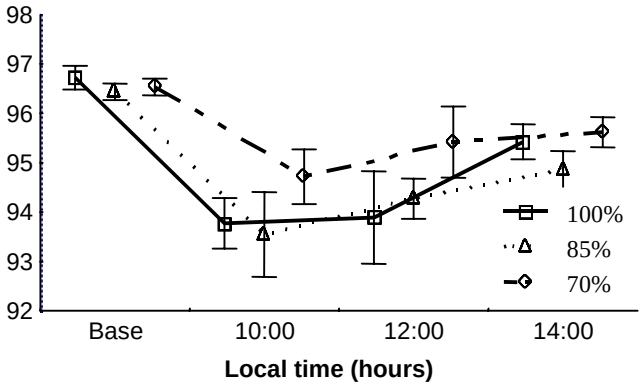

Figure 2. Diurnal variations of relative water content (%) in coffee leaves growing at different sunlight levels. Each point represents the mean of six replicates

Other results in that respect indicated that there were not differences in the growth and CO_2 assimilation between the full sunlight and 50 % sun light treatments, probably because the growth irradiance of 50 % plants was on average 850 mmol×m^{-2}×s^{-1}, which is well above the photosynthetic light saturation for both shade grown plants (300 μmol×m^{-2}×s^{-1}) and sunlight grown plants (600 μmol×m^{-2}×s^{-1}) (5, 6).

Photosynthetic pigment content. The irradiance regime influenced statistically on chlorophyll *a, b* and Chl *a+b* content (Table II). The coffee plants grown under 85 % solar exposition showed the highest values of chlorophyll content oscillating around 2.01, 1.08 and 2.88 mg×g^{-1} (leaf fresh weight) for Chl *a*, *b* and *a+b* respectively, while the low value was observed in the 100 and 70 % levels without significant differences between the last ones.

Table II. Variations in the photosynthetic pigment contents ofcoffee tree leaves growing at different sunlight levels. All values are expressed in mg.g (MF)$^{-1}$

Irradiance levels (%)	Cl *a*	Cl *b*	Cl *a+b*	Cl *a/b*	Carotene
100	1.70 b	1.030 b	2.730 b	1.660	0.3900
85	2.01 a	1.200 a	2.220 a	1.670	0.4500
70	1.84 b	1.090 b	2.930 b	1.680	0.4100
SEx	0.030	0.018	0.048	0.013	0.0085
P level	0.035	0.046	0.034	0.820	0.1000

Means followed by the same letter within a column are not significantly different

However, sunlight did not significantly affect the *a/b* chlorophyll ratio, indicating that the size of photosystems change very little with irradiance (6) and coffee plant adaptability to shade conditions. Similar results were obtained by comparing different nitrogen supplements and irradiance levels in young coffee trees (6). On the other hand, carotene content was not significantly affected by sunlight levels.

The decreasing in chlorophyll content under high irradiance regimes could reduce leaf absorbance and, consequently, reduce the stress caused by high temperatures under these conditions (15).

The observed decline in chlorophyll content in 100 % treatment may be mostly due to a reduced chlorophyll *a* content, which would probably inhibit thylacoid formation and alter grannum stacking profile (6, 16). In general, the contents of chlorophyll *a* and *b* are relatively lower than the ones showed in other papers (17).

Relative water content (RWC) and transpiration. It is accepted that coffee leaves maintain a high water content (higher than 90 %) under field conditions (18), due to the efficient stomata control and coriaceous constitution of leaves. In that respect, similar daily patterns of RWC in all three irradiance levels were observed at the base and 14:00 h, with a slight increase in 70 % plant at midday (Figure 2). The rest of the treatments showed a similar pattern. On the other hand, it is well documented that estimates of RWC were little affected by light levels when imbibition took place in the dark (18).

The highest RWC showed by 85 % treated plants could be due to the lowest transpiration rate observed under those conditions (Figure 3), that could contribute to maintain a better water status in the time of maximal water demand, independently of soil moisture. In that respect, results indicate that differences in soil moisture (Figure 1) do not influence significantly leaf water status, because of the highest RWC showed by the plant under all sunlight conditions.

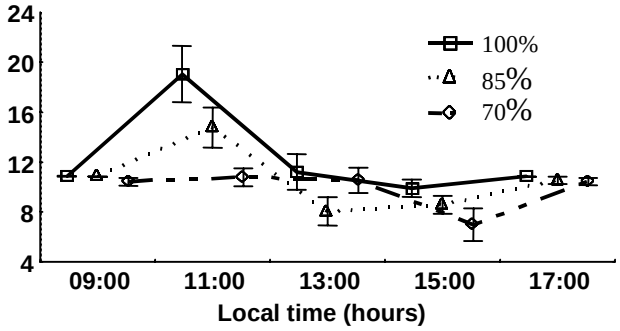

Figure 3. Time course of transpiration (mg(H_2O)·dm^{-2} min^{-1}) in coffee plant leaves grown at different sunlight levels. Each point represents a mean of six replicates

Some results indicated that RWC decrease slightly when soil moisture is low and this decreasing is even more remarkable when soil moisture is under a critical value (below field capacity). Similar results were obtained (13, 19). These authors did not get any RWC answer to solar exposition, but a positive relation with soil moisture was observed, which was markedly lower in shade plantation.

The highest transpiration value was observed for 100 % treatment at midday (11:00 h) followed by 85 and 17 % respectively. In the other day time, transpiration rate was similar in the three treatments. In that respect, some results indicated that transpiration in young coffee plants increased when increasing the irradiance in cloudy days, but in sunny days this increment was not observed (20).

That result at midday could be associated with the highest stomata conductance observed in sun plants, because as it was reported before (21), stomatal conductance was 54 % greater in *Coffea arabica* L. plants than the 80 % solar exposed plants and there were no differences in the stomatal conductance among the plants grown in 100 and 50 % solar exposition. Thus, the ratio between CO_2 assimilation and stomatal conductance (A/g), an indicator of the intrinsic water efficiency, was higher in plants grown under high and medium irradiance than under low irradiance.

The results showed in this work indicate that coffee plants grow better and have a better water status and chlorophyll content under slight sunlight conditions, which indicate the adaptability of coffee plants to moderated sunlight conditions. The highest transpiration rate at full sunlight was mainly observed at midday.

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